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Extended-Range Aircraft Tracking
[Unclassified Title]

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Radar Techniques Branch
Radar Division

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ABSTRACT
[Secret]

As part of the evaluation of the Madre radar system at the Chesapeake Bay Annex of the Naval Research Laboratory, data on a number of controlled over-the-horizon aircraft flights have been taken. Of particular interest is a flight which took place on 29 November 1962. The plane was a P3V (similar to the commercial Electra) and it was flying at an altitude of 24,000 ft from Lajes, Azores, to Norfolk, Virginia. The radar operated at 18.036 Mc/s with 4.6 Mw peak power. The plane was tracked over a great circle ground range from 1978 naut mi to 1391 naut mi. Radar cross-section measurements of the plane are included in this report, as well as an idealized treatment of the four-path over-the-horizon case.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

NRL Problem R02-23
Projects RF 001-02-41-4007, and
AF MIPR (30-602) 63-2928, (30-602) 63-2929,
and (30-602) 63-2995

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EXTENDED-RANGE AIRCRAFT TRACKING
[Unclassified Title]

INTRODUCTION

A part of the Naval Research Laboratory high-frequency radar mission is to furnish feasibility and specification data for the extension of radar range by using ionospheric refraction. The installation, located at the Chesapeake Bay Annex (CBA) of the Naval Research Laboratory (NRL), is a high-power, coherent, pulse doppler system (1) which employs earth-backscatter rejection filters able to handle in excess of 70-db clutter-to-signal ratios (2). After clutter filtering, a zero frequency i-f is sampled and stored with range segregation on a magnetic drum or disk using a packing ratio of 82,800 to 1. The previous 20 sec of signal information is continuously available for study in each 1/180-sec interval because of the time compression. The form of analysis used for the results given herein consists of a complete doppler-versus-range analysis for each time period of 1.8 sec. The resolution bandwidth is the equivalent of 1/3 cps (3,4).

In this report, radar display data taken of a flight made specifically for NRL use is given. The flight took place on 29 November 1962. The aircraft was a P3V (similar to the commercial Electra), and it flew at an altitude of 24,000 ft from Lajes, Azores, to Norfolk, Virginia. Radar tracking was performed between great circle ground ranges of 1978 naut mi and 1391 naut mi from the Chesapeake Bay Annex of NRL. Apparent aircraft echoing cross sections for this P3V are given, and the variations in apparent echoing area are discussed.

EXPERIMENTAL RESULTS

During the controlled P3V flight of 29 November 1962, the radar operated on 18.036 Mc/s with 4.6 Mw peak power, 60 kw average power, and a free-space antenna gain of 19.6 db. Figure 1 shows an amplitude-vs-range distribution of earth backscatter, in the direction of the flight, that was obtained during the test. The higher level backscatter extends from 975 naut mi to about 2000 naut mi, and this is the region in which the flight was tracked.

Figures 2(a) and (b) show a sequence of range-velocity-intensity display scans during the portion of the flight from about 12:18:09 p.m. to 12:32:09 p.m. EST. Time after 12:15 p.m. is indicated below each frame in minutes and seconds. The ordinate in each frame indicates doppler frequency (from which we obtain velocity) from 0 to 45 cps, while the abscissa indicates approximate radar range from 1350 to 1800 naut mi. Range and range-rate strobes are used for precise target logging. The P3V return appears at (200,18) in the first frame of Fig. 2(a), and a calibration signal appears at (240,12). The target moves to (90,18) in the last frame of Fig. 2(b). During this 14-min period the radar range measured by the range strobe changes by 80 naut mi. This corresponds to a range rate of 343 knots. The average range-rate strobe reading during the same time was 347 knots.

Figure 3 shows the P3V apparent radar cross section as the plane closed in range. The equation used to find the cross section is

$$\frac{(4\pi)^3 R^4 P_r}{G^2 \lambda^2 P_t}$$

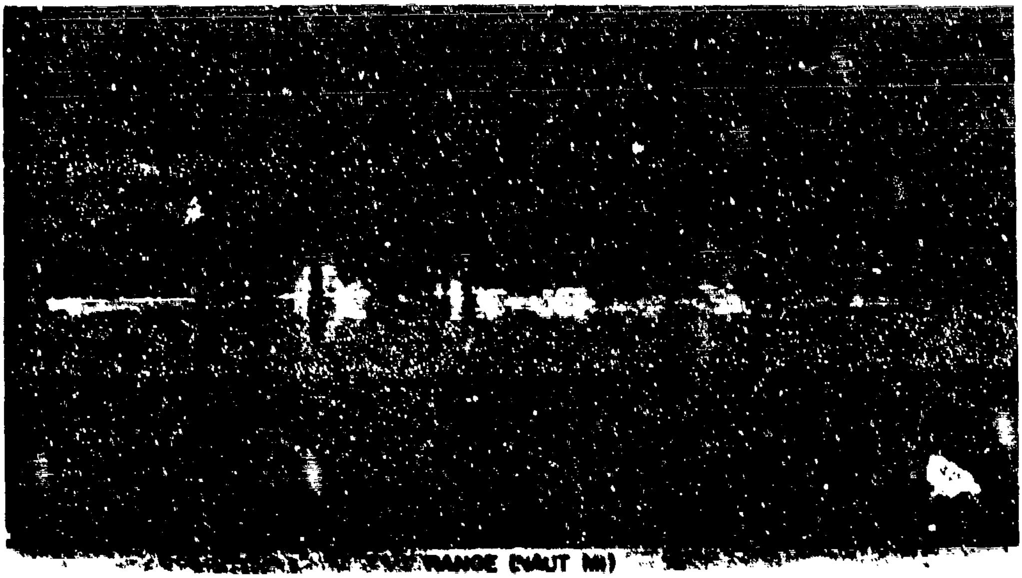


Fig. 1 - Amplitude-vs-range distribution of earth backscatter during P3V flight of 29 Nov. 1962

where P_r and P_t are the received and transmitted powers, respectively, R is the slant range to the target, and G is the maximum one-way antenna gain (25.6 db). This equation does not take into account any loss, other than spreading loss, due to transmission in the medium. Computed cross-section values will be lower than those resulting if the medium loss factor were included. The task of even roughly presenting loss figures in the medium for the paths involved in long-distance over-the-horizon (OTH) detections is far from simple, and such losses have been ignored. The dashed portions of Fig. 3 indicate times when the radar was inoperative. Received signal amplitudes are taken every minute; in ten cases the echo was not present at the reading time. These cases correspond to zero cross section and are carried as such in computing average and median values. The zero cross-section values are plotted on Fig. 3 along the base line, which corresponds to a cross section of 10 sq m. The median value for the radar cross section is 370 sq m and the average is 760 sq m. In computing, a maximum available antenna gain of 25.6 db is used since 6 db is added to the free-space gain of 19.6 db to account for placement of the antenna over ground. There will be times when the target energy doesn't come into the antenna on the nose of a lobe, and again the computed target cross section will be lower than if the actual antenna gain had been used.

Fig. 4(a) shows a doppler time history of the 6-min portion of this P3V flight when the plane was in the 1570-naut-mi slant range region. For this type of presentation the incoming signals are range gated with a 300-μsec gate which moves with the target. The aircraft doppler track appears as a broken line. This technique allows one to observe the target situation from minutes in the past until the present time and, in this respect, it gives a doppler time history of the target.

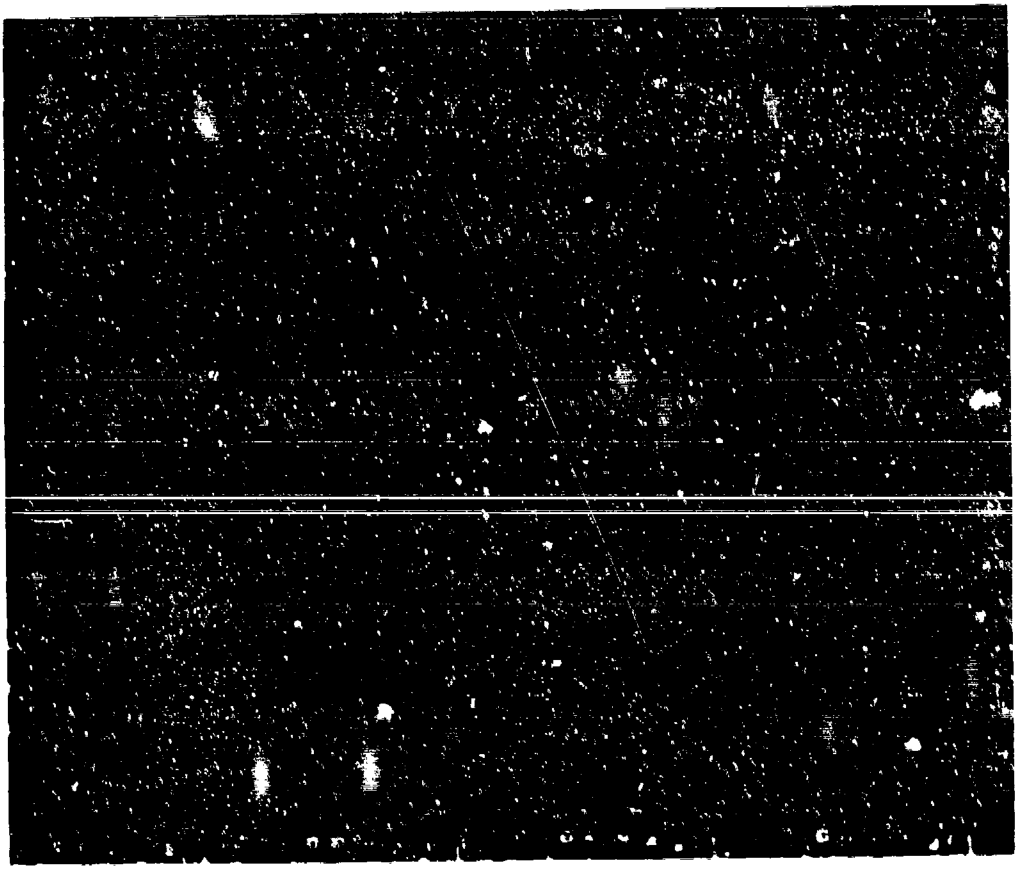


Fig. 2(a) - Sequence of range-velocity-intensity display scans for P3V flight. Primary display of flight from 12:18:09 to 12:28:14 p.m. EST.

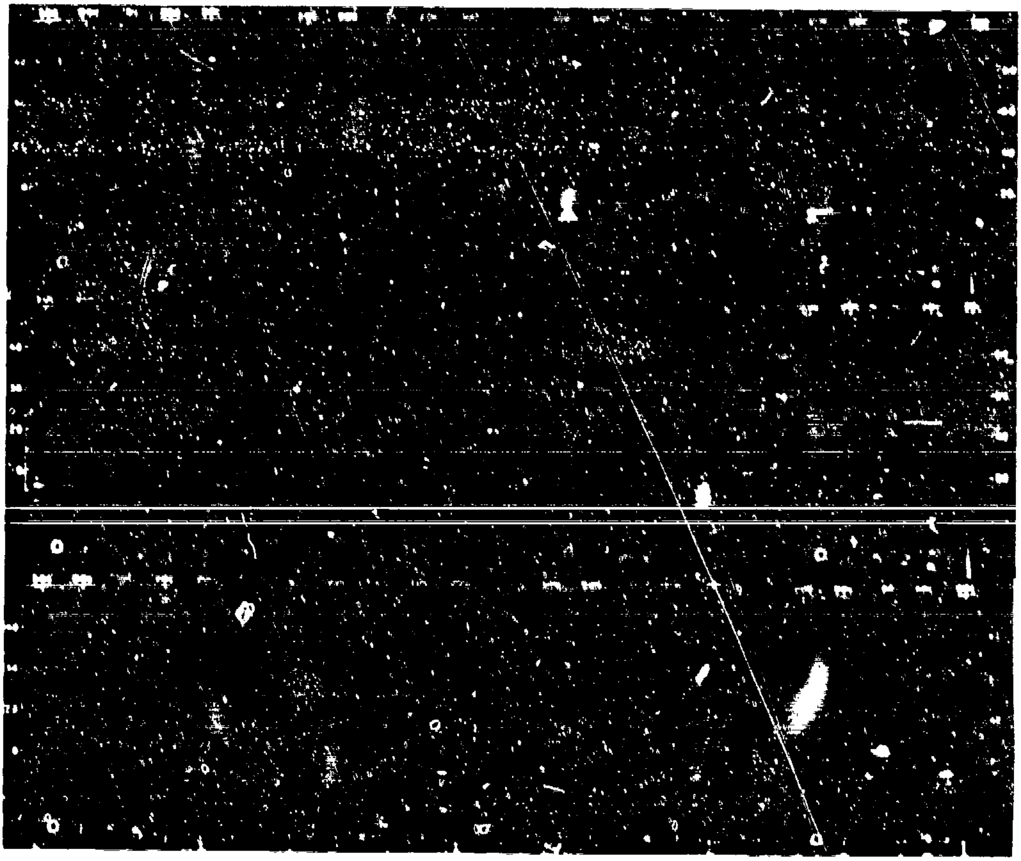


Fig. 2(b) - Sequence of range-velocity-intensity display scans for P3V flight. Primary display of flight from 12:25:40 to 12:32:00 p.m. EST.

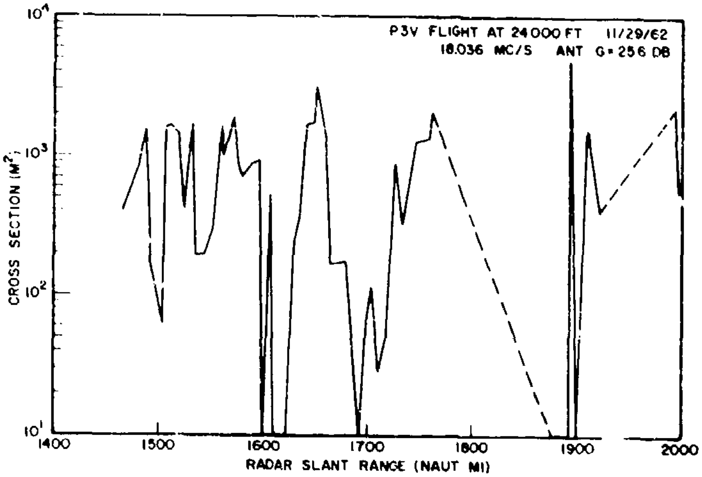
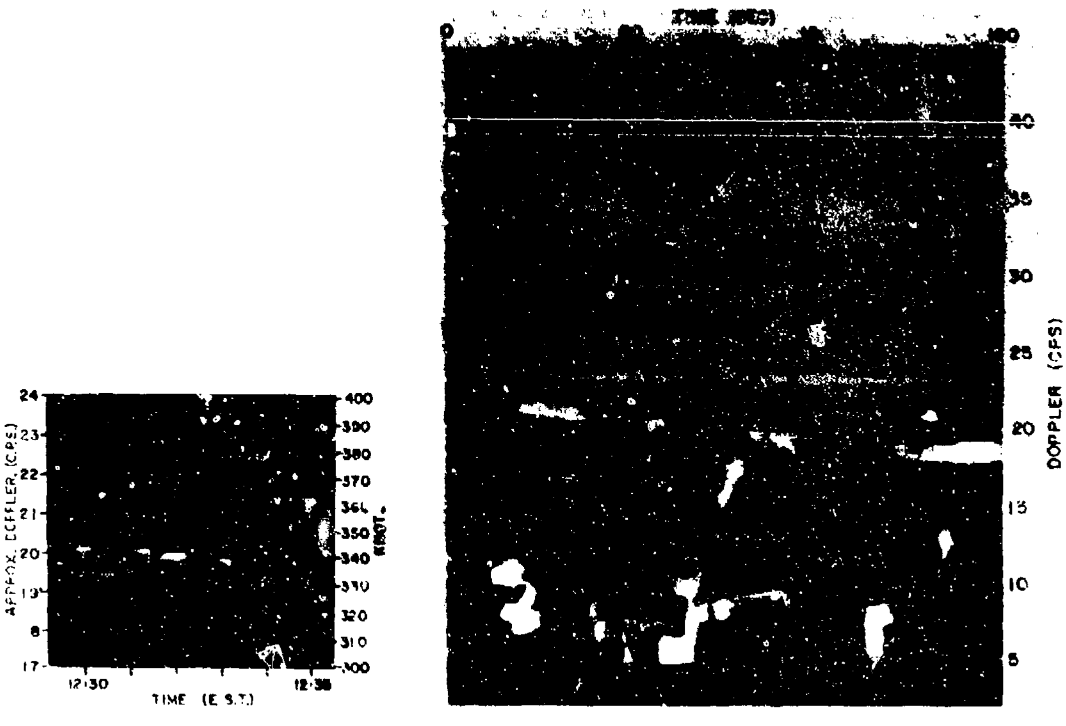


Fig. 3 - Radar cross section during P3V flight



(a)

(b)

Fig. 4 - Doppler time history plots of (a) P3V aircraft and (b) an aircraft detected during AMR test 3797

Figure 4(b) is another example of this type of analysis. It shows 3 min of doppler time history for an aircraft observed while the radar was set up for observation of AMR test 3797, the A2 Polaris launch of 23 August 1963. In this analysis mode the incoming signals are range gated with a 225-μsec gate. The aircraft track appears as a broken line in the 20-cps doppler region. The range gate ran from 740 to 758 naut mi and was in an optimum position for this aircraft, but the gate was out too far in range for the best missile effect. The missile signature shows after 60 sec and smears upward past the essentially horizontal aircraft track. The doppler time history technique allows one to observe the target situation from minutes in the past until the present time.

Figure 5 compares aircraft great-circle over-the-ground range to CBA, as derived from the navigator's position reports, with slant range taken from the radar display. The difference between slant range and ground range can be estimated roughly with data such as given in Fig. 1, and it can be estimated more precisely with complete knowledge of the prevailing ionospheric conditions.

The P3V data given above were taken on a transatlantic path at times when few other targets were present. It is of interest to show a radar display taken when viewing an area of greater aircraft population. Figure 6 shows aircraft returns on the radar doppler-range display when looking over the continental USA. This observation was a by-product of a setup for the observation of a West Coast missile launch and was made with a smaller gain antenna. Operating parameters for this setup were as follows:

Operating frequency - 18.036 Mc/s

Antenna bearing - 279° (i.e., looking west from NRL-CBA)

Antenna - 3 db, beamwidth 30°, free-space gain 11.6 db

Power output - 100 kw (average)

Pulse repetition frequency (prf) - 90 per sec

1st-hop backscatter range - 1000 naut mi to 1950 naut mi

Date and time - 12/13/63, 3:35 p.m. EST.

The receiver was gated on for the range intervals 450-900, 1350-1800, 2250-2700, etc., naut mi. The backscatter conditions indicated that the observed returns could only come from the 1350 to 1800-naut-mi range. Figure 6 shows doppler frequency along the ordinate, from 0 to 45 cps, and the range from 1350 to 1800 naut mi is shown along the abscissa. The large signal at 30 cps and 1700 naut mi is a calibration signal which corresponds to a 10-μV peak-to-peak signal at the antenna terminals. A target giving the same signal strength at this range would have a cross section of $1.156 \cdot 10^4$ sq m for an antenna gain 6 db above the 11.6-db free-space gain. There are at least nine aircraft echoes in this display, which encompasses a range depth of 450 naut mi, situated west of Denver, Colorado, with azimuthal coverage from Helena, Montana, in the north to White Sands, New Mexico, in the south.

APPARENT ECHOING CROSS SECTION

A discussion of transmission medium effects upon apparent echoing cross section may be helpful in studying the aircraft detection problem. Three idealized cases will be treated.

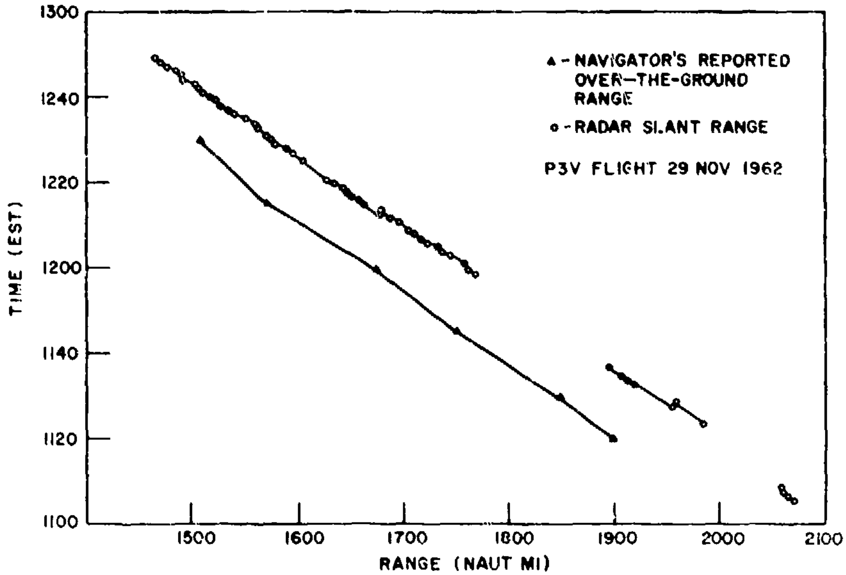


Fig. 5 - Navigator-reported over-the-ground range compared with radar slant range for P3V flight

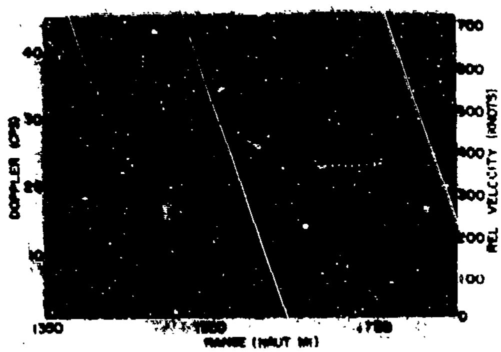


Fig. 6 - Aircraft targets viewed over interior of continental USA with radar facility at CBA

Case I: Consider an antenna and a target in free space with the antenna being used for both transmitting and receiving (Fig. 7(a)). The power density S_t at the target is $S_t = P_t G_0/(4\pi R^2)$ where P_t is the power into the antenna, G_0 is the free-space gain of the antenna, and R is the range to the target. The power density S_r at the antenna due to the echo from the target is $S_r = S_t \sigma/(4\pi R^2)$ where σ is the target echoing cross section. The cross section for the free-space condition will be used to define $\sigma_0 = 4\pi R^2 S_r/S_t$. Since $S_r = P_r/A$, where P_r is power available for the receiver and $A = G_o \lambda^2/4\pi$ is the capture area of the antenna with λ being the wavelength,

$$\sigma_o = \frac{4\pi R^2 S_r}{S_t} = \frac{P_r (4\pi)^3 R^4}{P_t G_o^2 \lambda^2}.$$

Case II: For this case the same antenna and target are placed over a conducting surface. The antenna orientation is such that maximum gain is parallel to the conducting surface. In Fig. 7(b) radiation from the antenna at A can reach the target at P by the path AP and by path ABP. Assuming that no loss occurs from the reflection at B and that ABP - AP << AP, the electric field at P will be twice the free-space value E_o when the electrical path length ABP differs from AP by $n\lambda$ and will be zero when the path length difference is $(n + 1/2)\lambda$. As the elevation angle ϕ is increased from zero to 90 degrees, the number of maxima where the field is $2E_o$ is $2h/\lambda$ where h is the antenna height. Since power is proportional to E^2, the maximum power density at P is $S \propto (2E_o)^2$, or four times the free-space value. Applying the same argument to the echo paths from the target to the receiver gives another increase in power by a factor of four. Thus, to calculate σ_o, $4G_o$ would be used in the place of G_o when P is at a point of maximum field.

Case III: In this case the target is placed over the horizon and is illuminated via the ionosphere. Figure 7(c) shows the target illuminated by four different paths, and if the four are in phase, $S_t \propto (4E_o)^2 = 16E_o^2$. On the return to the receiving antenna, another increase by a factor of sixteen with respect to the free-space case would be realized. To calculate σ_o in an idealized lossless situation where the radiation arrived at the target in phase, $16G_o$ would be used in the place of G_o.

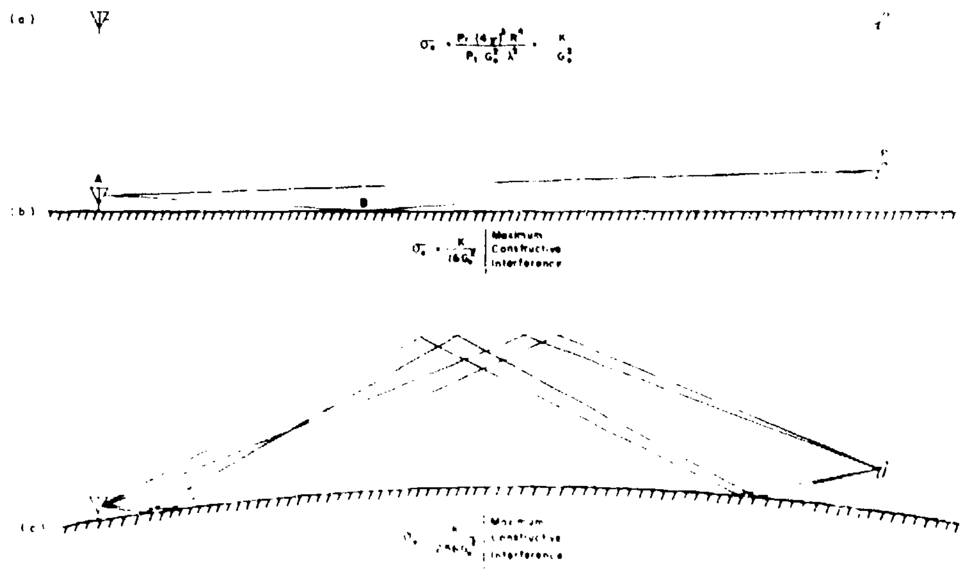
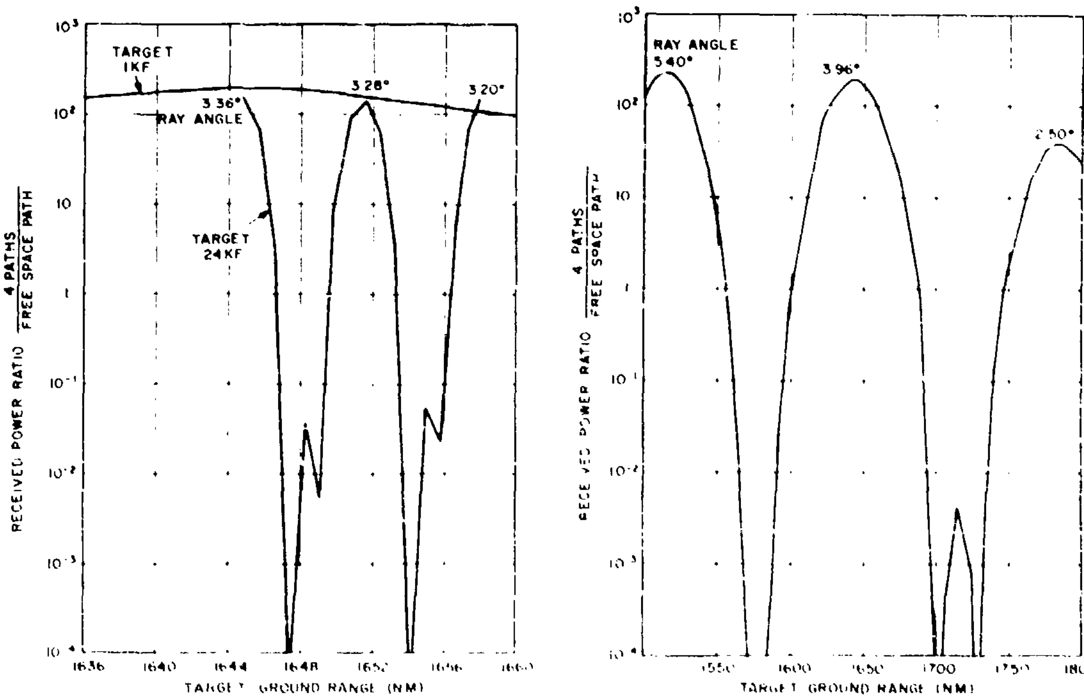


Fig. 7 - Geometrically distinct paths for (a) free-space, (b) line-of-sight, and (c) OTH propagation

The NRL antenna used in tracking aircraft over the horizon has a comparatively narrow beamwidth in the horizontal plane, but it has free-space directivity in the vertical plane of 12.5 to 25 degrees between the 3-db points over the design frequency range. The antenna height of 166 ft gives a fairly small number of lobes in the vertical plane. The 3-db points of the lowest two lobes are probably 4 degrees apart, yet they illuminate a ground range hundreds of miles in extent via the ionosphere.

A different situation exists at the target end of the OTH path. Here the target is usually thousands of feet above the earth's surface, and lobe structure due to target height above the earth is quite extensive. For example, for an aircraft flying at 24,000 ft, an operating frequency of 18.036 Mc/s would give 880 lobes in the vertical plane. With a moderately fast aircraft, target returns could easily go through maxima and minima at the rate of one per minute. The effective cross section computed from the amplitude of OTH aircraft echoes would vary, due to this cause alone, from a zero value to a value 24 db greater than σ_0.

Based on a simplified model, i.e., considering only spreading loss and four (ideal) paths, Fig. 8 shows how the power received from an OTH target will vary as a function of over-the-ground target range for the four-path case. The free-space reference is a hypothetical, single, free-space path which does not involve any ground or ionospheric reflection. The



(a) (b)

Fig. 8 - Computed rece[illegible] of target over-the-ground range: (a) target at 24 and 1 kft, and (b) expanded graph of target at 1-kft height. Transmitting antenna height was chosen as 160 ft and ionospheric height as 300 km.

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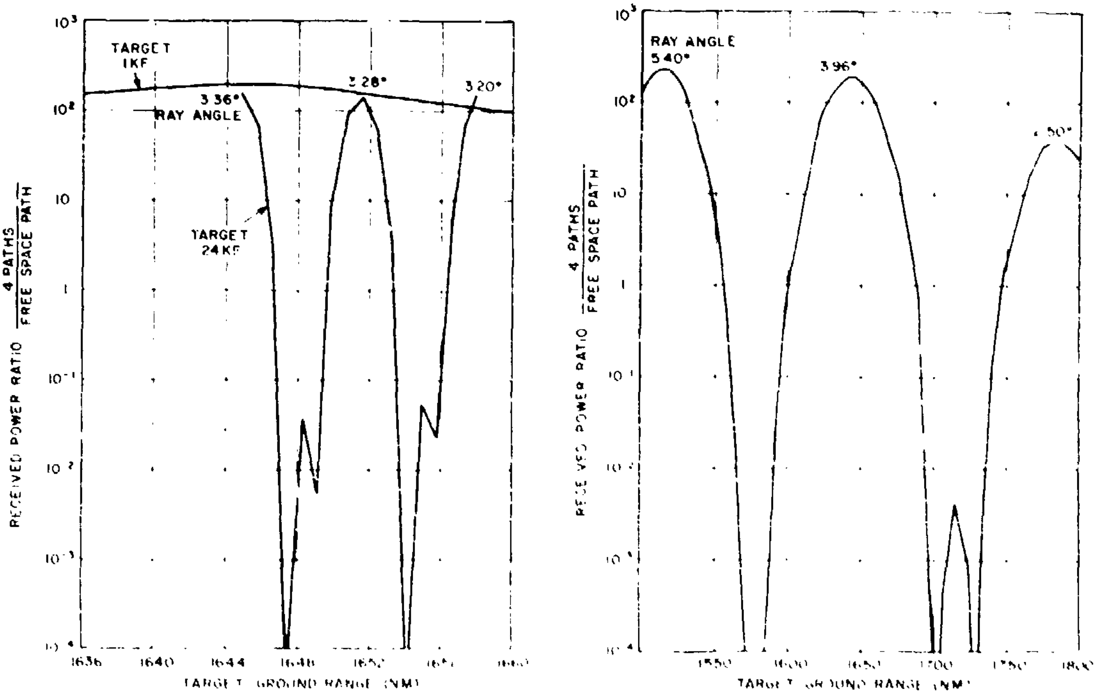

(a) (b)

Fig. 8 - Computed received power ratio as a function of target over-the-ground range: (a) target at 24 and 1 kft, and (b) expanded graph of target at 1-kft height. Transmitting antenna height was chosen as 166 ft and ionospheric height as 300 km.

data shown were computed using a G-15 computer. Target heights of 1 kft (1000 ft) and 24 kft are indicated. The height factor affects the time it takes a moving target to go through a maximum and minimum cycle. The table below shows the time for the returns from a 400-knot target to go from a maximum value to the next maximum value for this simplified model. The target is on a great-circle course which passes over the radar site.

Target Altitude (kft)	Over-the-Ground Speed (knots)	Max to Max Time (min)
1	400	21
24	400	1

In real life the ionosphere does not reflect exactly like a perfect mirror. This difference from the ideal case treated above tends to apply a smoothing to the signal peaks and nulls, and at times even introduce additional peaks and nulls. However, the results shown in Fig. 8 and the table illustrate a difference between low-altitude and high-altitude detection requirements. That is, a longer period of surveillance is required in the detection of low-altitude targets.

COMMENTS

In this report, the results of tracking one transatlantic P3V flight have been treated in some detail. One hf frequency, 18.036 Mc/s, was used to obtain adequate coverage of the interval between 1000 and 2000 naut mi distance from the radar. The P3V was tracked almost continuously for the distance between 1475 and 2000 naut mi except for two periods when the radar was not operating. After the aircraft closed to 1475 naut mi, tracking was terminated due to demand for a different radar use; continued observation was possible in to about 1000 naut mi. This example is illustrative of what can be done with an hf extended range radar.

An important feature of hf OTH radars is that aircraft targets can be detected at any altitude as long as they have sufficient relative velocity. The fading pattern of targets is dependent upon altitude to some extent, with the faster fade rates being associated with higher target altitudes.

Thousands of real-time OTH aircraft detections have been made with the NRL radar in the 500 to 2000-naut-mi interval. In hundreds of cases a study of aircraft echo has been made by tracking for some distance and recording received signal amplitudes (5-7). The aircraft have ranged from the F100 (38-ft wing span and 47-ft length) to the larger KC-135 and have included piston and turbo-prop types. Exclusive of times of ionospheric disturbance, or storm, and times when the required operating frequency was outside the capability of this experimental radar, fair illumination of a portion of the distance between 500 and 2000 naut mi has been always possible.

The following are the essential features of the radar:

a. One-way antenna gain of approximately 20 db,

b. Radiated power of 60 to 100 kw average, 4.6 Mw peak,

c. In excess of 70-db rejection of earth backscatter, and

d. 1/3 cps bandwidth predetection signal filter.

It is felt that sufficient experience has been accumulated to estimate system requirements for one-hop OTH aircraft detection. Principal deficiencies in knowledge are due to limited experience and to the use of frequencies above 13.5 Mc/s.

REFERENCES

1. Boyd, F.E., and Rohlfs, D.C., "A Very-High-Power High-Frequency Pulse Transmitter and Antennas," NRL Report 5903 (Secret Report, Unclassified Title), May 1963

2. McGeogh, J.E., Jensen, G.K., and Uniacke, C.L., "A 100-KC Quartz Crystal Comb Rejection Filter," NRL Report 5589 (Confidential Report, Unclassified Title), Feb. 1961

3. Page, R.M., and George, S.F., "Magnetic Drum Storage Applied to Surveillance Radar," NRL Report 4878 (Confidential Report, Unclassified Title), Jan. 1957

4. Wyman, F.E., and Zettle, E.N., "Magnetic Drum Storage Cross Correlation Radar," NRL Report 5023 (Secret Report, Unclassified Title), Nov. 1957

5. Gager, F.M., Headrick, W.C., Morgan, G.A., Utley, F.H., and Zettle, E.N., "Madre Performance, Part 1 - Observations of January 18 and 25, 1962," NRL Report 5862 (Secret Report, Unclassified Title), Dec. 1962

6. Gager, F.M., Headrick, W.C., Morgan, G.A., Rohlfs, D.C., Tesauro, C.B., and Zettle, E.N., "Madre Performance, Part 2 - Observations of February 8, 1962," NRL Report 5898 (Secret Report, Unclassified Title), Feb. 1963

7. Gager, F.M., Morgan, G.A., Tesauro, C.B., Skaggs, G.A., and Zettle, E.N., "Madre Performance, Part 3 - Observations of February 12, 1962," NRL Report 5991 (Secret Report, Unclassified Title), Aug. 1963

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As part of the evaluation of the Madre radar system at the Chesapeake Bay Annex of the Naval Research Laboratory, data on a number of controlled over-the-horizon aircraft flights have been taken. Of particular interest is a flight which took place on 29 November 1962. The plane was a P3v (similar to the commercial Electra) and it was flying at an altitude of 24,000 ft from Lajes, Azores, to Norfolk, Virginia. The radar operated at 18.036 Mc/s with 4.6 Mw peak power. The plane was tracked over a great circle ground range from 1978 naut mi to 1391 naut mi. Radar cross-section measurements of the plane are included in this report, as well as an idealized treatment of the four-path over-the-horizon case.

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